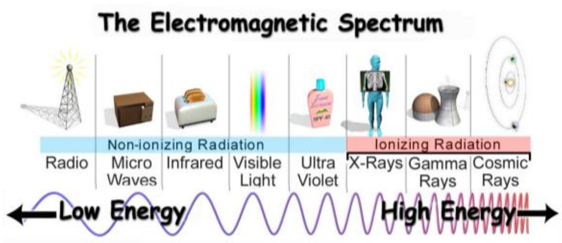
Chernobyl Documentary
Radiation Primer

To understand some of the concepts we will present in this documentary, it is important to first review some basic radiation terminology and characteristics.

The word 'radiation' has many meanings. There are different types of radiation, many which are not harmful at all. *[Graphic - electromagnetic spectrum]* Television waves, radio waves, and radar are all examples of radiation, and none of these cause harm to living organisms. These types of radiation do not have enough energy to cause damage to living tissue, and are called *non-ionizing radiation*.



The other general category of radiation is called *ionizing radiation* which does have enough energy to cause damage to living tissue. Ionization is a destructive process that causes atoms or molecules to lose electrons. X-rays, cosmic rays, and nuclear radiation are types of ionizing radiation.

Many radioactive materials occur naturally. For example, granite contains remnant radioactive isotopes from the formation of the earth, and when granite erodes, these radioisotopes are carried away as sand and clay that form the soil around us – there are beaches in Brazil with such high natural radiation levels that they have restricted access. Sand and clay are also used to make building materials such as brick and concrete, which may emit very low levels of radioactivity. Other naturally occurring radioactive isotopes are created when cosmic rays interact with atoms in the atmosphere. We are also exposed to manmade radioactive materials that have been released into the environment. Nuclear weapons testing has contributed to a slight increase in background radiation. You may also be exposed to radiation through medical procedures such as x-rays. You are exposed to radiation, known as background radiation, every day, and the amount of background radiation you are exposed to depends on where you live.

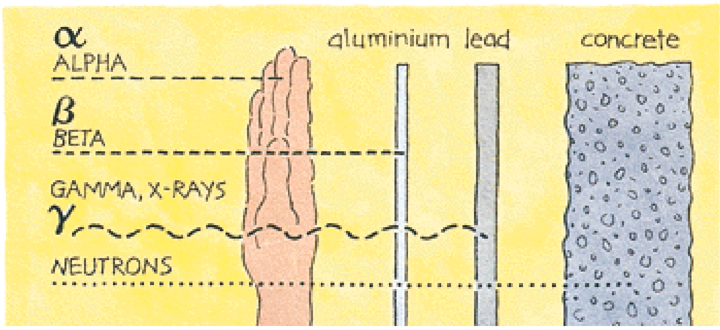
Nuclear radiation, which comes from the nucleus of an atom, is the type of radiation that most people think of when discussing radioactivity, and our discussion will focus on nuclear radiation. Remember that an atom is made of neutrons and protons that form the nucleus and electrons that orbit around the nucleus. *[show atom structure graphic]* There are over100 different types of atoms and each has a specific number of protons that identifies the atom as an *element*, such as oxygen or iron. For example, the element uranium always has 92 protons. However, the number of neutrons can vary. Elements with the same number of protons but different numbers of neutrons are called *isotopes*. For example, uranium can have 138 neutrons or 146 neutrons. Uranium with 146 neutrons is known as the isotope U-238.

[Graphic: table of uranium isotopes]

Radionuclide	Protons	Neutrons
Uranium 230	92	138
Uranium 235	92	143

Uranium 238	92	146

Certain isotopes are unstable because they have too many protons or neutrons. They essentially have too much energy and they release that extra energy to become more stable. This happens spontaneously and is called *radioactive decay*. These isotopes are radioactive. Radioactive isotopes release energy primarily as four types of radiation: alpha particles, beta particles, gamma rays, and neutrons. Each type of radiation has different ability to penetrate materials *[see graphic]*.



Nuclear radiation is measured in several different ways. When we talk about the amount of radioactive material, we don't use weigh or volume because it does not have much meaning. Instead, we talk about the amount of radiation emitted from the material, or *activity* of the material.

[NOTE – We could potentially lose this whole alpha, beta, gamma, neutron breakdown, as there isn't a place later in the documentary where we go into the types of radiation given off by Chernobyl]

They release energy primarily as four types of radiation: alpha, beta, gamma, and neutrons. We will discuss the characteristics of each.

Alpha particles are two protons and two neutrons ejected from the nucleus of a radioactive atom. *[graphic - animation of alpha decay]* They have lots of energy but can only travel up to an inch or two in air and are easily stopped by a piece of paper. They are also easily stopped by the outer layer of your skin which is made of several layers of dead skin cells. However, serious damage can occur if you inhale or ingest an alpha emitter. In fact, internal alpha radiation exposure is the most damaging type of radiation. An unfortunate example is the former Russian KGB officer Alexander Litvinenko who ingested a lethal quantity of the rare alpha emitter polonium-210. Exposure to alpha particles can mostly be eliminated by wearing a respirator.

Beta particles are electrons ejected from the nucleus. Beta radiation can travel several feet in air and can penetrate up to a half inch into human tissue. It takes thick plastic or metal to stop beta radiation. A respirator will protect a responder from inhaling beta emitters and protective suits will provide some protection from beta radiation by preventing contamination of bare skin. *[show animation of beta decay]*

Gamma rays are electromagnetic energy (not particles) that comes from the nucleus, usually at the same time alpha or beta particles are emitted. They travel many yards in air and penetrate right through the human body. Gamma rays are the most serious external exposure hazard and there is no practical protective suit that will stop gamma radiation. It takes about a foot of lead or several feet of concrete to stop all gamma radiation. A respirator is still beneficial to prevent ingesting gamma emitters. Although gamma is hard to stop, it is easy to detect. Based on the amount detected, responders can take actions to protect themselves, for example, by limiting the time they are exposed. *[graphic - animation of gamma decay]*

The last type of ionizing radiation is neutron radiation. This comes from the nucleus but is rarely emitted spontaneously. Instead neutron radiation is created by nuclear reactions such as those in a power plant or detonation of a nuclear bomb. Neutrons can travel very far in air, up to a mile and can penetrate through the human body. They are not easily stopped or detected. It takes many feet of concrete to stop neutrons. There is no protective equipment for neutron radiation.

This illustration summarizes the penetrating power of the four types of ionizing radiation that we have discussed. {show graphic}

Activity is usually measured in *curies,* which is the amount of radiation emitted by one gram of radium. A curie is equal to 37 billion disintegrations per second, or 37 billion gamma rays, alpha particles, or beta particles per second. The physical amount of material to make one curie could be one gram of radium or thousands of kilograms of some other radioactive material. That is why the amount of material is not important but the activity of the material is!

The activity of a radioactive material is closely related to the material's *half-life,* or is the amount of time it takes for the radioactivity of the material to decrease by half. For example, if the half life on isotope is one day, then after one day, half of the material will have decayed. The remaining half is still radioactive, so after another day half of this portion will have decayed. The decay process continues until no more radioactive material remains. Depending on the starting amount, it takes about 7 to 10 half-lives before the radioactivity is near background levels of radiation.

Each radioactive isotope has a unique half-life. *[graphic - half life table]* Half-lives of some isotopes are billions of years; other isotopes have half-lives of just a few seconds. Isotopes with shorter half-lives have higher activity, and tend to pose more serious health threats. This makes sense because a short half life means a material is emitting a lot of radiation in a short time.

Isotope	**Half-Life**	**Origin**	**Uses**
Uranium-238	4.5 billion years	Naturally occurring	Armor-piercing projectiles
Carbon-14	5,730 years	Naturally occurring	Carbon dating fossils
Cesium-137	30 years	Manmade	Geiger counters
Iodine-131	8 days	Manmade	Treat thyroid cancer
Technetium-99m	6 hours	Manmade	Medical imaging
Strontium-97	9 seconds	Manmade	None

Half-life is also important from the perspective of environmental cleanup. If a material with a long half-life is released then it will take a long time to decay to a harmless level. Cesium-137, one of the isotopes released by the Chernobyl accident, has a half life of 30 years. Cesium-137 continues to this day to be the primary contaminant of concern in most of the areas affected by the Chernobyl accident. After 32 years, almost half of the Cesium-137 released by the accident remains. On the other hand, one of the other major isotopes released by the accident (Iodine-131) has a half-life of 8 days. Iodine-131 was a major health concern shortly after the accident, but essentially all of it has decayed away by now and it is no longer a problem.

We need to cover one more topic before we go back to our story about Chernobyl*: nuclear reactions*. A nuclear reaction is one where the nucleus of an atom is changed, releasing incredible amounts of energy. At Hiroshima and Nagasaki, *uncontrolled* nuclear reactions occurred in a split second, releasing huge amounts of energy and radioactive isotopes with short half-lives. Most of these short half-life isotopes have decayed away, and the cities of Hiroshima and Nagasaki are now vibrant urban centers. *Controlled* nuclear reactions such as those used at nuclear power plants, on the other hand, take place over longer periods and create more isotopes with long half-lives. Both controlled and uncontrolled nuclear reactions create long and short half-life radioactive isotopes, but a controlled nuclear reaction creates a much higher proportion of long half-life isotopes. This is a fundamental reason that Hiroshima and Nagasaki are active urban centers with large populations, but the exclusion zone around the Chernobyl plant is expected to be uninhabitable for 1,000 years.

[NOTE – We may need to get into the discussion of dose later in the documentary, especially when we kick into the residual levels of contamination that are left. At this point, we've defined too many new terms, yet hit the highlights – isotopes are created by reactions, and they can be radioactive.

The short half-life isotopes are the problem because they release a lot of energy fast. The longer half lives are an ongoing problem because they really don't go away.

In a similar vein, we may want to introduce the idea of fallout and hot particles here in the primer rather than later. I chose to put that later in the story, as this is a long section with a lot of new terms and it's pretty dry – best to keep it short and focused if we can.]

Note the last radionuclide in the table, uranium-235. This is an important radionuclide in our story about Chernobyl. Although it has a very long half-life and is not very radioactive, uranium-235 is a fissile material. This means it can undergo fission which is when a nucleus is split releases lots of energy in the process. Uranium-235 is made into fuel for a nuclear power plant or an atomic bomb. The uranium-235 used in an atomic bomb undergoes an uncontrolled reaction releasing incredible amounts of energy in a split second for destructive purposes. Nuclear reactor fuel undergoes fission in a controlled manner and the energy released is harnessed to make electricity.

As the nuclei of uranium-235 fission they are turned into numerous other radionuclides, like cesium-137 and strontium-90. These radionuclides have much shorter half-lives than uranium-235, thus are much more radioactive and potentially dangerous to us. Cesium-137 we mentioned previously as the primary contaminant of concern from the Chernobyl accident because it is persistent with a half-life of 30 years. Many more radionuclides with much shorter half-lives were released from the accident and have since decayed to background levels.

Before we get into the other units of measurement we should review the difference between exposure and dose. Radioactive materials emit radiation in all directions which creates a "radiation field." If the radiation is gamma then the radiation field can extend over a large area. Exposure is when you are in a radiation field, basically, the radiation is bombarding your body. As the radiation interacts with your cells damage will occur. The damage is called dose. Dose is cumulative, so the more radiation that interacts with your body the higher your dose. Now how is the radiation field and dose measured?

The radiation field is measured using various field portable instruments with very sensitive detectors. There are detectors for all types of radiation. Detectors that measure gamma typically provide readings in roentgen [note to narrator: pronounced ran-'kin]. The technical definition is not important, however, it is only applicable to measurement of gamma radiation. Many instruments measure the radiation field over time and readings are in roentgen per hour. However, because these instruments are so sensitive they can detect background levels of radiation. Background radiation is at very low levels of radiation. It is so low that we have to measure micro amounts. Remember that micro means one millionth. Thus, these instruments measure in the microroentgen per hour levels. As we stated before, background is different everywhere but in most areas in the United States background gamma radiation is typically between 10 and 30 microroentgen per hour. To put these measurements into perspective, we are usually not concerned about our immediate health and safety until levels are in the milliroentgen per hour range or about a thousand times higher. And we don't become really concerned until levels are over a million times higher than background!

Dose is measured in units of roentgen equivalent man or rem. Rem is related to the amount of damage to the human body so it does not work for animals or plants, which by the way, are usually much more resilient to radiation than human beings. The international version of a rem is the sievert and just like the becquerel, only the United States and Russia use the rem. But the conversion is easy because there are 100 rem in one sievert. For a frame of reference, the average person in the United States receives about 360 millirem per year from background radiation. This is a very low dose and as far as we know not harmful to us.

Let's put the various measurement altogether. {show Units Illustrated animation slide} The amount of radioactivity of a material is measured in curies. It emits a radiation field that can be measured with a radiation instrument in roentgen. The damage to human is measures in rem.

{show Exposure and Dose animation slide} We consider all radiation to have a harmful affect on us and there is an accumulated affect. The more radiation absorbed by your body the higher the dose. Dose is accumulated as long as we are exposed to the radiation field. We like to reduce our dose as much as possible, both short and long term exposures. [do we want to talk about ALARA? – probably not]

Background - however, we do not start to see immediate biological changes in our bodies until a dose of 25 rem or nearly 70 times our yearly background dose. At this dose there will be some temporary changes in our white blood cell counts but that is about it. The long term consequences of a 25 rem dose are essentially unknown. However, we do know that there is an increased chance of getting cancer and increase chance of dying from the cancer due to radiation exposure. In the United States, there is about a 20 percent change that you will die from cancer. If you receive one rem of dose then your chance of dying from cancer increases by about seven hundredth of a percent. Thus, a 25 rem dose increases our chance of dying from cancer by less than two percent. {show Cancer Statistic table}

Exposure	**Chance of Dying from Cancer**
Background	20%
1 rem	20.07%
25 rem	21.8%
100 rem	27%

It is important to understand that a dose of 25 rem is extraordinary. Occupational limits are set at 5 rem per year and very few workers that work with radiological materials reach that level in a year, most don't reach that level in their entire work career. [do we want to discuss guidance levels for emergency responders which is 25 rem to save lives and greater than 25 rem by volunteer only according to EPA?]

We looked at the half lives of a few naturally occurring and manmade radioactive materials. There are many more of each with the manmade radionuclides usually made for useful purposes. Most of the manmade radionuclides have a fairly high activity and in sufficient quantities can be deadly. Examples are cobalt-60 with a five year half life used for various industrial and medical purposes, like cancer treatment. {show table of Radionuclide Uses in the United States}

Radionuclide	**Half-Life**	**Uses**
Americium 241	433 years	Smoke detectors
Cobalt 60	5 years	Cancer treatment
Gallium 67	3 days	Medical diagnosis
Hydrogen 3	12 years	Luminous exit signs
Iridium 192	74 days	Test integrity of pipe welds
Uranium 235	704,000,000 years	Nuclear power plant fuel

More information to add to primer:
Hot particle
Fallout
Environmental damage—fate and transport *radioisotope dispersal patterns and persistence in the environment*